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The Scientific Revolution in Europe and its Impact on Chinese Cosmology during the 16th-18th Centuries

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ABSTRACT: The scientific revolution, which developed in Western Europe during the 16th-18th centuries, was one of the most significant fruits of the activity of European universities. The cultural movement of Renaissance, born in Italy a century earlier, which moved the center of attention of scholars on man, 'blacksmith of his destiny' and on his dignity, with a marked curiosity for the laws of nature, greatly contributed to it. Another propulsive factor were the maritime expeditions across the Atlantic, the Pacific and the Indian Oceans, promoted by the kingdoms of Portugal and Spain at the end of the 'Reconquista', between the 15th and the 16th centuries. Their vessels crossed the Equator Line, discovering new lands and new skies. Celestial Mechanics was at the center of that peaceful revolution, owing to the initiative of scholars as Nicolaus Copernicus, Galileo Galilei, Tycho Brahe, Johannes Kepler, Isaac Newton. The Jesuit missionaries, sent to China by the Roman Catholic Church with evangelizing purposes, propagated among the scholars of the imperial court the use of the astronomical telescope and the adoption of the experimental method in science. Unfortunately, the Roman Catholic Church condemned in the same years the propagation of the heliocentric theory, because it contradicted the Bible, of which the Church considered to be its exclusive interpreter. This was a hindrance to the advancement of modern Celestial Mechanics in the Far East, until the Church ceased to obstruct the heliocentric theory toward the middle of the 18th century. It took another century for that theory to be fully accepted by Chinese scholars.

KEYWORDS: Ptolemaic Geocentric Universe, Copernican Heliocentric System, Tychonic Geo-heliocentric System, Kepler's Solar System

1. INTRODUCTION

The *scientific revolution*, which took place during the 16th-18th centuries, was one of the most significant fruits of the activity of European universities and the astronomical observatories established across the continent in medieval times. The European cultural panorama was not restricted to the academic world: the philosophical movement of *Humanism*, born in Italy during the 14th century from the study of classical antiquity by initiative of the scholar and poet Francesco Petrarca (1304-1374), moved the center of attention of scholars from Heaven to man, '*blacksmith of his destiny*'. The subsequent art movement of *Renaissance*, born in Florence towards the end of the same century, stimulated the interest of scholars for Nature and its laws. Over the course of two centuries *Renaissance* spread from Tuscany to the entire Italian peninsula and to the rest of the continent (Monfasani, 2020). Artists like Leonardo da Vinci (1452-1519) and Michelangelo Buonarroti (1475-1564), thinkers like Erasmus from Rotterdam (1466-1536), Michel de Montaigne (1533-1592) and Rene' Descartes (1596-1650), writers like Miguel de Cervantes (1547-1616) and William Shakespeare (1564-1616), were universal geniuses, capable of rejuvenating the way of thinking of the medieval man, transmitting to him enthusiasm for new discoveries in all sectors of knowledge.

As for Celestial Mechanics, European geo-political factors contributed to its extraordinary development: the maritime expeditions beyond the *Pillars of Hercules*[1] organized by the rulers of the Kingdoms of Portugal and Spain toward the end of the 15th century, after the conclusion of the *Reconquista*[2], forced the navigators to carefully turn their eyes to the sky. Under the Spanish flag the Italian navigator Christopher Columbus' sailed westwards from Spain across the Atlantic Ocean, reaching in 1492 the coasts of Central America, while the Portuguese Vasco da Gama, sailing eastwards, crossed South Africa and reached in 1498

[1] *Pillars of Hercules*: The Gibraltar Strait.

[2] *Reconquista*: the military campaigns that Christian kingdoms undertook against the Muslim kingdoms established in the Iberian Peninsula, which initiated in 718 A.D. and ended with the fall of the Nasrid kingdom of Granada in 1492.

the coasts of India. His countryman Jorge de Alvares, sailing in the same direction, reached in 1521 for the first time the coasts of China. Another Portuguese navigator, Fernão de Magalhães (better known as Ferdinand Magellan), trying to find a western route to Asia, crossed the South Atlantic Ocean, and, through the *Magellan Strait* in South America, succeeded in reaching the coasts of Asia. In the Northern Hemisphere those navigators were guided by the *Polar Star* while, crossing the Equator's Line, they discovered the *South Star* and other new constellations (Crowther, 2015).

A religious institution, the Roman Catholic Church, one of the leading spiritual powers of Western Europe, opposed the scientific achievements of two prominent European astronomers of those times, Nicolaus Copernicus and Galileo Galilei, but also exerted a positive role in the intercultural communication between Europe and the Far East through its *Jesuit Mission to China*. The Roman Catholic Church, guided by the Pope, witnessed in the first quarter of the 16th century the rebellion by the German monk Martin Luther, whose *Protestant Reform* soon spread over Central and Northern Europe, followed by the *Anglican Schism* in the Kingdom of England, John Calvin's *Protestant Movement* in France and the Low Countries, the *Presbyterian* movement in Scotland and the *Swiss Protestant Reformation*. The Pope reacted with a *Counter-Reform*, strongly reaffirming in the *Council of Trent* (1545-1563) the exclusive right of the Church to interpret the Bible and establishing, in 1542, the Holy Roman Inquisition with the task of monitoring compliance with what proclaimed by the Church. The penalties for offenders, in the countries ruled by Catholic princes, were severe, reaching death at the stake. The Roman Church established also, in 1540, the *Society of Jesus*, whose missionary monks were sent to Central and South America to directly evangelize the natives (following the Spanish and Portuguese colonizer), and to India and the Far East with the purpose of establish contacts with the rulers of those countries (following there a *top-down* evangelizing strategy). The Jesuit monks of the *China Mission* constituted a selected group of men with a sophisticated cultural background, ranging from Humanities to Mathematics, Physics, Astronomy and Applied Sciences. They all spent a training period at *St Paul College* in Macao to learn Chinese, before making themselves known at the Imperial Court in Peking through their scientific knowledge. Over the course of a few decades they made themselves useful to the rulers through their advanced astronomical knowledge.

Purpose of this review paper is to retrace the efforts undertaken by Jesuit missionaries in transmitting the foundation of modern Celestial Mechanics to the Chinese *élite* during late Ming and the Qing dynasties.

As indicated in the References section, the basic texts utilized in this research are K. Crowther (2015), J.S. Heilbron (2018), S. Drake (2017), D.E. Mungello (2005), J. Needham (1995), N. Sivin (1995), as well other research papers and volumes quoted in the text.

The paper is subdivided into the following sections: 1. Introduction, 2. Development of Celestial Mechanics in Europe during the 16th-18th Centuries, 3. Ancient Chinese Cosmology, 4. The Jesuit Mission in China 5, Conclusions. A References section concludes the paper.

2. DEVELOPMENT OF CELESTIAL MECHANICS IN EUROPE FROM PTOLEMY TO THE 16TH-18TH CENTURIES

The celestial models adopted in the West before the *Scientific Revolution* date back to the 4th century B.C., when the Greek philosophers Plato and Aristotle imagined the Earth as a stationary sphere, located at the center of the universe. Moon, Sun, Venus, Mercury, Mars, Jupiter, Saturn and the fixed stars were assumed to be located on several crystal spheres surrounding the Earth, rotating at different uniform speeds around the Earth. The spheres were composed of an incorruptible substance called *aether*.

The *Ptolemaic System* was developed by the Greek astronomer Claudius Ptolemaeus (Ptolemy) (100-170 A.D.) who, in his main astronomical work, the "*Almagest*" (*Greatest Astronomy Text*), similarly assumed that the Earth was a sphere, located in the center of the universe, and each planet (Moon and Sun included) was moved by a system of two spheres, one called *Deferent* (whose center point, called the *Eccentric*, was somehow displaced with respect to the Earth's center) and the other the *Epicycle*, a smaller sphere centered in the planet and embedded in the *Deferent*. A given planet then would move along a circular path on the *Epicycle* and, at the same time, the *Epicycle* would rotate around the *Deferent*. These combined movements would cause the given planet to move closer to and further away from the Earth at different times in its orbit, The model with *Epicycles* is in fact a very good approximation to an *elliptical* orbit with low *eccentricity*. The Ptolemaic order of spheres from Earth outward was the following: Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, Fixed Stars. An outermost moving sphere, the *Primum Mobile*, was introduced in the model, to account for the apparent daily motion of the Heavens around the Earth, producing the East-to-West rising and setting of the Sun and stars. In Figure 1 a sketch of the Ptolemaic System is given, where the small, dotted circles around the planets Mercury, Venus, Mars, Jupiter, Saturn (indicated by the capital letters B, C, D, E, F) represent their epicycles[3].

[3] According to Ptolemy, the composition of the circular motion of a planet around the Earth with the circular motion around the epicycle gives the actual trajectory of the planet.

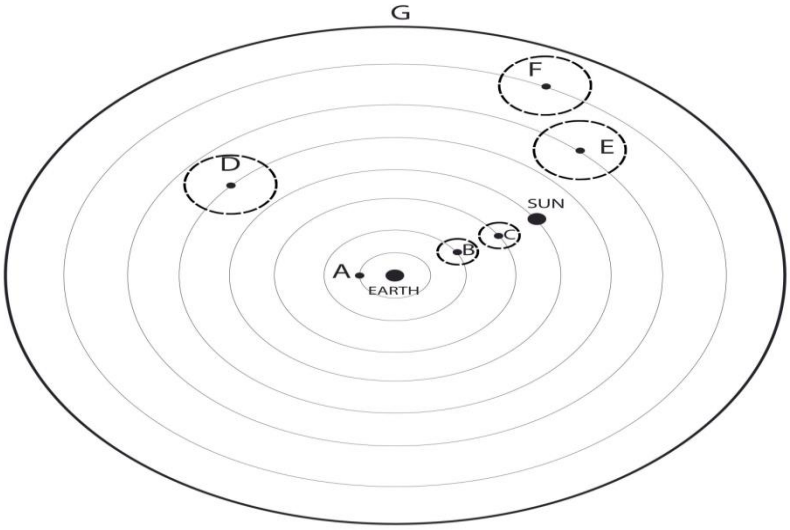

Figure 1 – Sketch of the Ptolemaic Model of the Universe

A: MOON; B: MERCURY; C: VENUS; D: MARS; E: JUPITER; F: SATURN; G: CELESTIAL SPHERE (STARS)

The path of the Scientific Revolution in *Philosophia Naturalis*[4] and Celestial Mechanics was rather arduous because it was opposed by two powerful institutions, the academic world, of Aristotelian tradition, and the Roman Catholic Church, which considered the *Geocentric System* of the Sky as absolute faith truth, basing it on the *Bible*. The establishment of the basic laws are mainly due to the joint efforts of the Pole scholar Mikołaj Kopernik (1473-1543), the Danish Tycho Brahe (1546-1601), the Italian Galileo Galilei (1564-1642), the German Johannes Kepler (1571-1630) and the English Isaac Newton (1643-1727) (Gingerich, 1993; Westfall, 2007*).*

Mikołaj Kopernik*,* better known as *Nicolaus Copernicus*, was born in the Polish city of Torun. From 1491 to 1495 he studied humanities at Krakow University, then moved to Italy, where from 1496 to 1501 studied Law and Philosophy at the University of Bologna, from 1501 to 1503 Medicine and Astronomy in Padua, and got a doctorate in Canon Law from the University of Ferrara. He finally returned to Poland, devoting himself to Astronomy, while performing administrative duties for the rulers of his country.

As the result of his accurate astronomical observations, he formulated a *Heliocentric Model* of the universe, placing a stationary Sun at the center of the Solar System, with the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn located at increasing distances from the Sun and rotating around it along circular orbits (Armitage, 1990). In 1543, the year of his death, he published a treatise entitled "*De revolutionibus orbium coelestium*" (*On the Revolutions of the Celestial Spheres*), where his *Heliocentric Model* was illustrated.

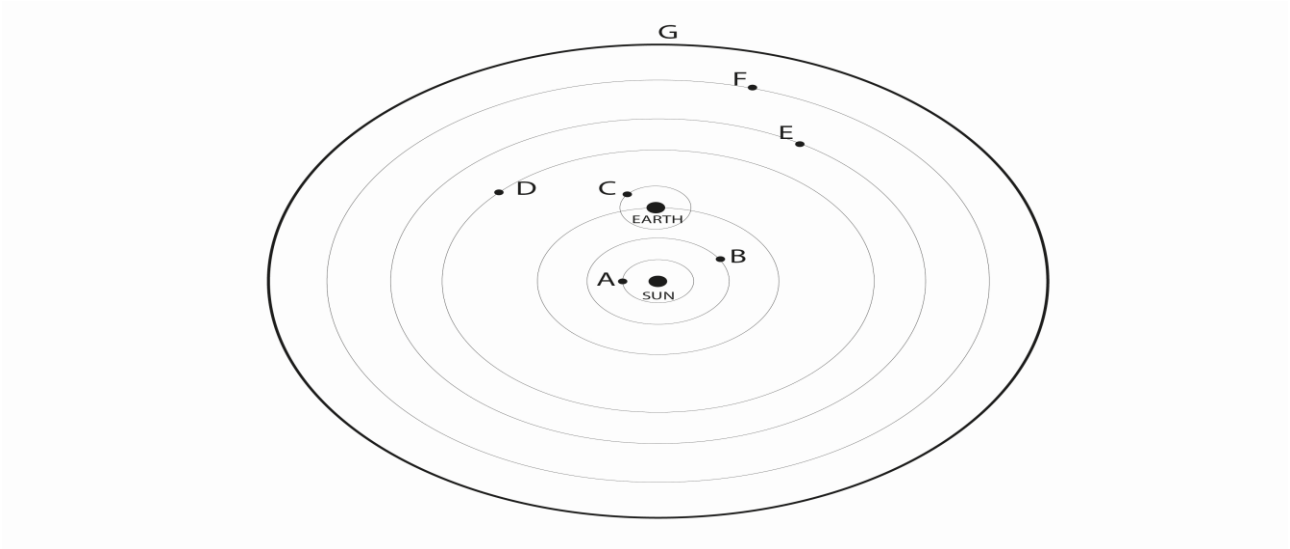

Figure 2- Sketch of the Copernican Solar System

[4] *Philosophia Naturalis*: Physical Sciences.

A: MERCURY; B: VENUS; C: MOON; D: MARS; E: JUPITER; F: SATURN; G: CELESTIAL SPHERE (STARS)

Copernicus' work appeared with a short unsigned preface, written by the theologian and astronomer Andrea Oseander (Hoseman), who took care to underline how the author considered his model as a simple mathematical construction, useful for calculations, but not necessarily true. Since the preface was anonymous, it was long understood to have been written by Copernicus himself. In 1543, the year of Copernicus' death, his treatise "*De revolutionibus orbium coelestium*" (*On the Revolutions of the Celestial Spheres*) was published.

At first, his astronomical system did not arouse any opposition from the Roman Catholic Church, which claimed absolute authority in astronomical matters as the unique authorized interpreter of the Holy Bible. The ruling Pope Clement VII was very pleased of Copernicus's *Heliocentric System* (Repcheck, 2007, 78–79, 184, 186).

In 1583 the Danish Tycho Brahe, director of the Imperial Astronomic Observatory in Prague, retained from the ancient *Ptolemaic System* the idea of Earth as a fixed center of the Universe, around which the Sun and Moon revolved, but he derived from Copernicus the idea that all other planets revolved around the Sun (and consequently they revolved in turn, together with the Sun, around the Earth). In both the *Tychonic* and the *Ptolemaic* systems, an outer sphere containing the fixed stars was assumed to revolve every day around the Earth. The *Tychonic* theory explained the observed variations of phase of Venus[5], for which the Ptolemaic system had no explanation (Gingerich,1993).

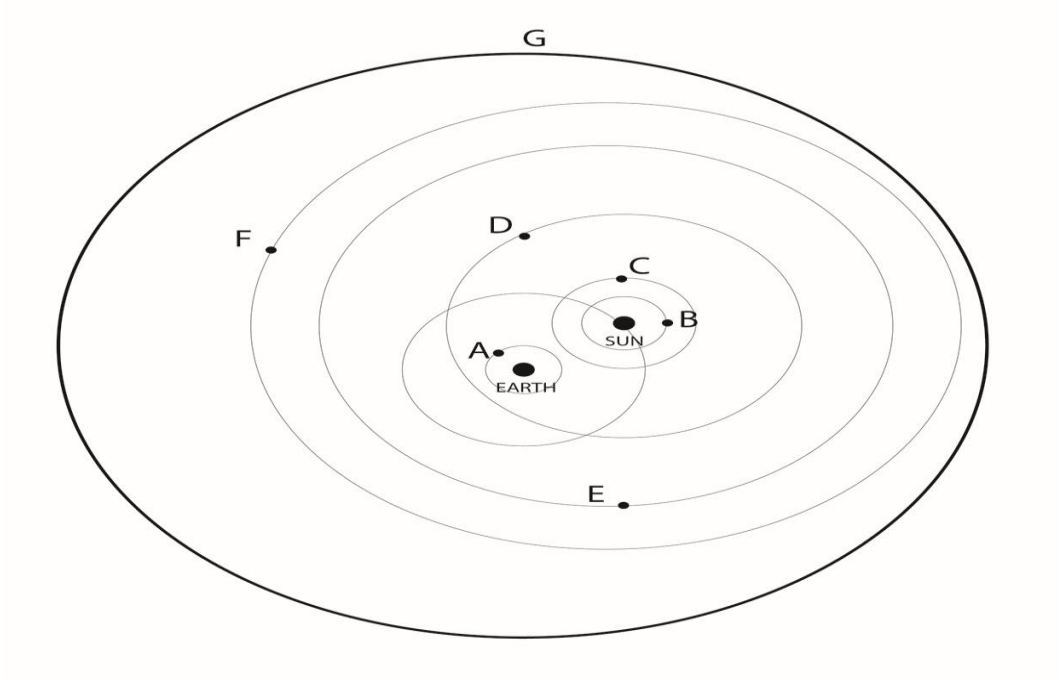

Figure 3 – Sketch of the Tychonic Model of the Universe

A: MOON; B: MERCURY; C: VENUS; D: MARS; E: JUPITER; F: SATURN; G: CELESTIAL SPHERE (STARS)

It was basically a mix between the *Geocentric* and the *Heliocentric Models* of the solar system. The Earth was placed, immobile, at the center of the Universe. The Moon and the Sun orbited around the Earth, while the other five planets known at the time (Mercury, Venus, Mars, Jupiter and Saturn) orbited around the Sun. The Tychonic system is perfectly equivalent to the Copernican system as regards the observation of the relative motions of the Earth and the other planets, once the origin of the *Reference System* is located in the center of the Earth[6]

The German Mathematician and Astronomer Johannes Kepler (1571-16309, convinced of the truth of the Copernican heliocentric model, published in 1596 "*Mysterium Cosmographicum*" (*The Cosmographic Mystery*), the first public defense of the Copernican model. He later improved Copernicus' model, once he became an assistant to Tycho Brahe in Prague and, afterwards, the *Imperial Mathematician* at the Court of the German Holy Emperor Rudolf II, in Prague.

By studying Brahe's data, he published in 1609 "*Astronomia Nova*" (*New Astronomy*), a treatise containing the following Astronomy Laws:

[5] The *Phases of Venus* are variations of lighting seen on the planet's surface, similar to lunar phases. The first recorded observations of them are thought to have been telescopic observations by Galileo Galilei in 1610.

[6] The *Geocentric* and the *Heliocentric Systems*, however, differ from each other with regard to the stars: the *parallax* of the stars and the *aberration of light* of fixed stars (shift of the angular position of the stars with respect to the Earth).

I *The planets move in elliptical orbits with the Sun at a focus.*

II *In their orbits around the Sun, the planets sweep out equal areas in equal times*.

In the triennium 1618-1621, Johannes Kepler published the "*Epitome Astronomiae Copernicanae*" (*Copernican Astronomic Compendium*) containing the additional '*Third Law*':

III *The squares of the times of the planets to complete one orbit are proportional to the cubes of their average distance from the Sun*

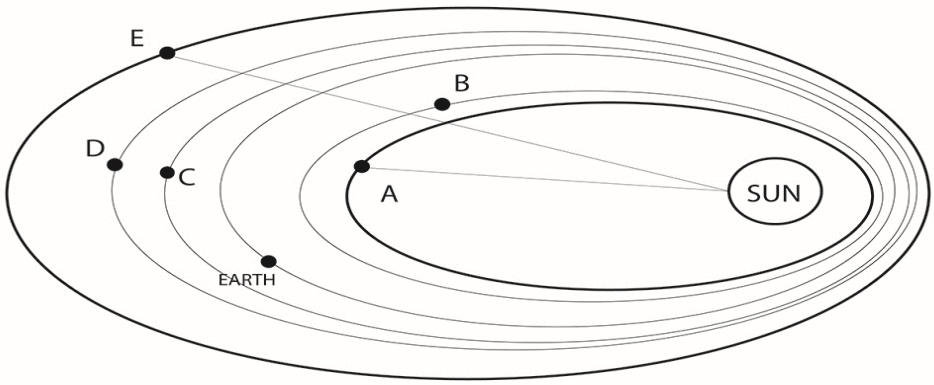

Figure 4 – Sketch of Kepler's Model of the Solar System

On March 5, 1616 the *Sacred Congregation of the Index*, created by Pope Pius V in 1571 for the purpose of examining publications suspected of doctrinal or moral errors (including them, in the positive case, in the *Index of Forbidden Books*) published a decree condemning the "*De revolutionibus orbium caelestium*" and including a general ban on all Copernican books ('*omnes libros idem docentes*'). From the perspective of the Church the *Heliocentric System* was not in agreement with the Bible, which assigned a privileged position to the Earth. The *Copernican Geocentric system*, on the other hand, denied this privileged position of the Earth with respect to other celestial bodies.

Johann Kepler's first volume of "*Epitome Astronomiae Copernicanae*" was also put on the *Index of Prohibited Books* on 28 February 1619. Kepler devoted himself to the composition of "*Tabulae Rudolphinae*" (*Rudolphine Tables*), a star catalogue and planetary tables, using observational data collected by Tycho Brahe, published in 1627. The main purpose of the *Rudolphine Tables* was to allow the accurate computation of the positions of the then known planets of the Solar System. When Tycho Brahe died in 1601, Kepler became the official Rudolf's *Imperial Mathematician*. When Emperor Rudolf died, in 1612, Kepler left Prague.

The Italian Mathematician and Astronomer Galileo Galilei took a strong position in favor of Copernicus' *Geocentric Model*. Born in Pisa, in the Grand Duchy of Tuscany, he attended there his first university studies in Medicine, Philosophy and Mathematics and undertook his first experiments on falling bodies, introducing the *experimental method* in the study of natural phenomena, proving that '*all falling bodies, irrespectively of their weight, take the same time to fall on the ground from a given height*'.

In 1590 he was invited by the rulers of the Venetian Republic to teach Geometry, Mechanics and Astronomy at the University of Padua. There he continued his studies on the movement of rigid bodies, finally arriving at the enunciation of the '*Inertia Principle*', according to which *'a body not subject to external forces, remains in a state of rest or moves with uniform rectilinear motion'*.

From the *Inertia Principle* descends the '*Galileo's Relativity Principle*'. Defining as *Inertial Reference System* any reference system in which the *Inertia Principle* holds, '*Galileo's Relativity Principle*' says that '*the laws of Mechanics have the same form in all Inertial Reference Systems*'.

While in Padua, Galileo as first improved an optical instrument devised for the observation of distant objects which had been invented in 1608 by the Dutch optician Hans Lippershey, thus creating the *astronomic telescope* for the study of celestial phenomena (King, 1955). Thanks to this instrument he discovered four satellites of the *Jupiter* planet, the *sunspots* and the irregularities of the surface of the Moon, finally publishing in Latin, in 1610, the "*Sidereus Nuncius*" (*The Messenger from the Stars*).

In that year he left Padua to Florence, under the invitation of the Grand Duke of Tuscany Cosimo II Medici, becoming his '*First Mathematician and Philosopher*'. The following year Galileo was in Rome, where he was received with great honors by Pope Paul V (1552-1621) and was accepted as a member by the *Accademia dei Lincei* (*Lincean Academy*), which had been established in that city in 1603 by Federico Cesi and other scholars, with the purpose of contributing to the development of the sciences.

In 1624 Galileo published "*Il Saggiatore*" (*The Essayer*), a treatise in which he exposed the fundamental points of his experimental research method. He wrote:

"*The philosophy of Nature is written in this great book that is continually open in front of our eyes (I say the universe), but it cannot be understood unless one first learns to understand the language and know the characters in which it is written. It is written in the language of mathematics, and the characters are triangles, circles, and other geometric figures, without which tools it is impossible to humanly understand a word of them; without these it is a vain wandering inside a dark labyrinth*."

Some years later, in 1632, Galilei published the "*Dialogue concerning the two chief world systems*" (*Dialogo sopra i due massimi sistemi del mondo*), a refutation of the *Ptolemaic-Aristotelian* system in favor of the *Copernican* system[7]. The Church, which had initially granted its *imprimatur* to this work, radically changed its position, inserting it in the *Index of forbidden books* in 1633 and, after a trial, condemned Galileo (after having forced him to repent) to perpetual house arrest in Arcetri, near Florence, not far from the convent where his two daughters were living as cloistered nuns, in a house offered to him by the Grand Duke of Tuscany. The motivation of the sentence was that his work called into question the Roman Catholic's interpretation of the Bible. Before his death, which took place in 1642, Galileo succeeded in dictating to his secretary (made available to him by the Grand Duke) his last scientific work, "*Discourses and Mathematical Demonstrations Relating to Two New Sciences*" **(***Discorsi e dimostrazioni matematiche intorno a due nuove scienze*), published in Leiden by *Elzevier* in 1638. In it, the author illustrated and demonstrated the principles of the *uniformly accelerated motion* (later formalized by Newton as the *Second principle of Dynamics of rigid bodies*) and posed additionally the foundations of the *Theory of Construction Science* (Drake, 2017).

The final triumph of *Heliocentrism* took place by initiative of Sir Isaac Newton. He was born on 25th December 1642 at Whoolsthorpe Manor, in the county of Lincolnshire, in the Kingdom of England, and in 1661 was admitted as a student of Philosophy and Mathematics at *Trinity College*, in Cambridge. As a student, he began to develop a mathematical theory of *Differential Calculus* and in 1667 he became a *Trinity Colle Fellow*. In 1687 he published his fundamental work, the "*Philosophiae Naturalis Principia Mathematica*" (*Mathematical Principles of Natural Philosophy*), where he formulated the basic principles of *Dynamics* (a branch of Physics that deals with *forces* and the bodies' movement), namely the *Law of Universal Attraction* and the *Three Principles of the Dynamics of Rigid Bodies.*

Law of universal gravitation[8]

A body of mass m_1, attracts any other body B_2 (with mass m_2) with a force F, which is directed from the center of mass of B_2 toward the center of mass of B_1, and whose magnitude is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers of mass[9].

Newton's Three Principles of the Dynamics of Rigid Bodies

- ***First Principle***: Galileo's *Inertia Principle*.
- ***Second Principle***: a force **F**, acting on a body with mass m, gives it an acceleration **a** according to the proportionality relation: **F** = m **a**.
- ***Third Principle*** (Law of *Action and Reaction*)**:** if a body B_1 exerts on body B_2 a force **F**, at the same time the second body exerts on the first a force **F'** which is equal to **F** in magnitude, but with has opposed direction (**F'** = **- F**).

Newton demonstrated that the motion of celestial bodies could be accounted for by these physical laws and improved Galileo's telescope. He further developed a Theory of Colors, observing that a Quartz prism separates white light into the colors of the visible spectrum. His work on light was collected in his "Optics", published in 1704. He finally studied the speed of sounds and introduced the notion of a Newtonian Fluid (Westfall, 2007).

To complete this Section, we must add that the Sun, the Moon and six of the planets of the *Solar System* rotate around their axes in a counterclockwise direction (*prograde rotation*), while the planets Venus and Uranus exhibit a clockwise direction (*retrograde rotation*). The Moon orbits the Earth once every 27.322 days. It also takes approximately 27 days to rotate once on its

[7] Recent theories reveal the inaccuracy of the Galilean proof of the tides in favor of Heliocentrism.

[8]The physical entities under study are of two types, *scalars* and *vector valued* ones. *Scalars* are physical entities which have only a *magnitude* (expressed by a real number, followed by the indication of the measurement's unit) such as the *mass* of a body. *Vector valued* physical entities, such as the *force* acting on a body, and the *velocity* and *acceleration* of a moving body, are characterized by *magnitude* and *direction*. In this text, bold characters indicate *vector valued* physical entities (as *Force*, *Velocity*, *Acceleration*).

[9] In mathematical terms, the Law of Universal Gravitation can be expressed in the following form:

$$\mathbf{F} = \mathbf{G}\, m_1.m2 / r^2,$$

where **G** *is a vector valued physical constant, oriented toward the Earth's center of gravity, and whose magnitude is the 'universal proportionality constant G.*

axis (*synchronous rotation*). As a result, the moon does not seem to rotate but it appears from Earth to be keeping almost perfectly still (McBride et al., 2004). Owing to this rotation around its North-South axis, the Earth is crushed at his *North and South Poles*, assuming the shape of an *Ellipsoid*. We must add that Earth's rotation axis has an inclination of about 23° 27' (varying from 22.1° to 24.5°, with a periodicity of about 40.000 years) with respect to the perpendicular to the Ecliptic (the plane of Earth's orbit around the Sun). This inclination of the rotation axis is responsible for the Earth' seasonal changes. The Earth's *Equatorial Plane* has an inclination of 23o 27' with respect to the *Ecliptic Plane* (the plane on which the Earth's orbit is located).

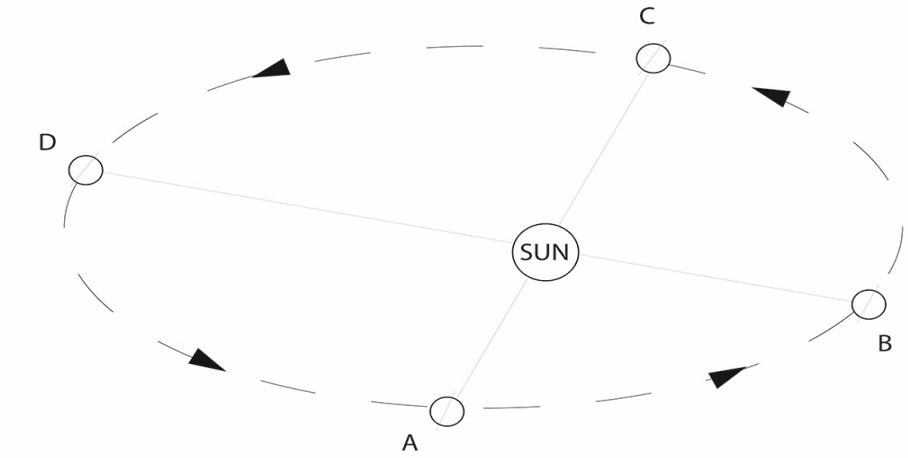

Figure 5 – Sketch of the Earth's movement around the Sun

A: Autumn Equinox (Northern Hemisphere), Spring Equinox (Southern Hemisphere)
B: Winter Solstice (Northern Hemisphere), Summer Solstice (Southern Hemisphere)
C: Spring Equinox (Northern Hemisphere), Autumn Equinox (Southern Henisphere)
D: Summer Solstice (Northern Hemisphere), Winter Solstice (Southern Hemisphere)
AC: Equinox Line; BD: Solstice Line

3. ANCIENT CHINESE COSMOLOGY

The first traces of astronomical research in China date back to the third millennium B.C. Since the *Zhou* dynasty (1046-256 B.C.) Chinese rulers received the "*Mandate of Heaven*" (天命 *Tiānmìng*) to keep the Earth in total harmony with the Sky (Roberts, 1999). One of the main jobs of the rulers, receiving the '*Mandate of Heaven*' was to announce the first day of every month and predict lunar and solar eclipses. The emperor appointed a special group of imperial officers, who included astronomers, astrologers and meteorologists, which were ordered to monitor the sky, looking for astrological omens and astronomical phenomena. To locate these events, Chinese astronomers took care to describe the visible stars with great accuracy. One of the main functions of astronomy was for the purpose of timekeeping. The Chinese used a *lunisolar calendar*[10], but as the cycles of the Sun and the Moon are different, leap months had to be inserted regularly (Needham, 1995).

The first theory concerning the structure of the Earth and the Sky was that of the '*Celestial Dome*' (**盖天***gai tian*), a hemispherical cap which covered a flat Earth, followed by that of the '*Celestial Sphere*' (浑天 *hun tian*), a spherical Earth floating inside the Celestial Sphere. The astronomer Shi Shen (**石申**) (4th century B.C.) wrote "*The Astronomy*" (石氏天文, *Tianwen*) and a *Celestial Map*, where 121 stars, were positioned. Astronomers' primary interest was an accurate observation of the sky; the first stellar catalog to have come down to us was composed in the first century B.C. At the time of the Han Dynasty (202 B.C.-220 A.D.), another theory followed, that of the '*Light and Darkness*' (**宣夜***xuan ye*), which hypothesized that the celestial bodies were immersed in an empty and infinite space (a night pervading everything).

> '*The cosmological theories had to provide the theoretical sub-stratum to the enormous mass of data collected since the most remote times of astronomical observations*. *They also had to support the dominating philosophical doctrines: in particular, from the Han Dynasty onwards, Confucianism*' (Iannacone, 1990)

[10] *lunisolar calendar* = A *lunisolar calendar* is a calendar combining *lunar calendars* and *solar calendars*.

A great astronomic advancement was reached by Yu Xi (虞喜) (307-345 A.D.), who discovered the *Precession of the Equinoxes*[11], independently of the Greek astronomer Hipparchus (190-120 B.C.), and Zu Chongshi (祖冲之) (429-500 A.D.), who in 465 composed the "*Da Ming Calendar*" (大明历), which contains the description of 283 constellation present in the sky of the *Northern Hemisphere*. Some elements of Indian Astronomy reached China with the expansion of Buddhism, especially at the time of the Tang Dynasty (618-907 A.D.). The Buddhist monk and astronomer Yi Xing (一行) (683-727 A.D organized an *astrogeodetic survey* all over China, with the purpose of obtaining new astronomical data that would aid in the prediction of solar eclipses. (Xu, 2018). '*Heavenly bodies were allocated to terrestrial zones, especially 28 constellations roughly along the equator or the ecliptic, the seven stars of the Big Dipper (regarded as the carriage of heaven), and the five planets [Venus (the metal star), Jupiter (the wood star), Mercury (the water star), Mars (the fire star) and Saturn (the earth star), representing the Five Agents (metal, wood, water, fire and earth) on the time dimension)].*' (Xu, 2018).

Chinese astronomers divided the sky it in four regions, the *Black Turtle* (玄武 *Xuánwǔ*) in the North, the *White Tiger* (白虎 *Báihǔ*) in the East, the *Red Bird* (朱雀 *Zhūquè*) in the South and the *Green Dragon* (青龙 *Qīnglóng*) in the West, each one of them containing 7 constellations, for a total of 28 located in twenty-eight mansions called 宿 (Sù). (Ruggles, 2005).

The *Black Tortoise* (玄武*Xuánwǔ*) represented both North and Winter. A symbol of longevity, the tortoise of the North was often depicted together with a snake. The union of these two creatures was thought to have created the earth. It was also associated with the element *water*. It contained the following constellations: 角 (*Jiǎo= Horn*), 亢 (*Kàng=Neck*), 氐 (*Dǐ=Root*), 房(*Fáng=Room*), 心 (*Xīn=Heart*), 尾 (*Wěi =Tail*), 箕 (*Jī=Basket*).

The *Blue Dragon* (青龙 *Qing long*) represented both East and Spring; Unlike in western mythology, the dragon was rarely depicted as a malevolent force but generally considered to be both benevolent and auspicious. It was also often associated with the emperor and therefore linked to the Red Bird, associated with the empress. The dragon was associated with the element *Wood*. It contained the following constellations: 斗(*Dǒu=Southern Dipper*), 牛(*Niú= Ox*), 女(*Nǚ=Woman*), 虚(*Xū=Emptiness*), 危(*Wēi=Rooftop*), 室(*Shì= Encampment*), 壁(*Bì=Wall*).

The *Red Bird* (朱雀*Zhūquè*) represented the South and the Summer; the bird was sometimes seen as a phoenix and associated with *good fortune*. It was also often paired with the dragon. It was associated with the element *Fire*. It contained the following constellations:奎(*Kuí=Striding person*), 婁(*Lóu = Three Stars*), 胃(*Wèi=Stomach*), 昴(*Mǎo= Hairy head*), 毕(*Bì=Net*), 觜(*Zī=Turtle's Beak*), 参(*Shēn=Seven Stars*)

The *White Tiger* (白虎*Báihǔ*) represented the West and Autumn; The tiger was often seen as a protector and was associated with *Metal*- It contained the following constellations:

井(*Jǐng=Well*), 鬼(*Guǐ=Ghost*), 柳(*Liǔ=Willow*), 星(*Xīng=Star*), 张(*Zhāng=Leaf*), 翼(*Yì=Wing*), 軫(*Zhěn=Charriot*).

In the center there was the polar constellation of *Big Dipper* or *Plough* (北斗星 *Běidǒuxīng*) with the *Polar Star* in it. As for the planets, in Chinese cosmology *Venus* (金星 *Jīnxīng*) represented the *metal star*, Jupiter (木星 *Mùxīng*) the *wooden star*, Mercury (水星 *Shuǐxīng*) the *water star*, Mars (火星 *Huǒxīng*) the *fire star* and Saturn (土星 *Tǔxīng*) the *Earthen Star*, all together the *Five Agents* (*Metal, Wood, Water, Fire, Earth*). Most constellations were based on the works of Shi Shen (石申) and Gan De (甘德) who were astrologists during the period of Warring States (战国时代 *Zhànguó Shídài*) (481 – 221 B.C.). The major constellations and planets were assumed to be located in nine distinct layers of Sky, as viewed from the Earth, and their rotational period and path were accurately measured, as follows:

- the 1st layer of the sky was the closest to the Earth: it was the celestial domain of the Moon, which rotated from the west to the east along a circle completed in 27 days plus 7 hours 45 minutes;
- the 2nd layer of the sky was the celestial domain of the planet Mercury, rotating from the west to the east with the circle completed in 365 days plus 5 hours 45 minutes;
- the 3rd layer of the sky was the celestial domain of the planet Venus, rotating from the west to the east with the circle completed in 365 days plus 5 hours 45 minutes;
- the 4th layer of the sky was the celestial domain of the Sun, rotating from the west to the east with the circle completed in 365 days plus 5 hours 45 minutes;
- the 5th layer of the sky was the celestial domain of Mars, rotating from the west to the east with the circle completed in 1 year plus 321 days 23 hours 15 minutes;
- the 6th layer of the sky was the celestial domain of Jupiter, rotating from the west to the east with the circle completed in 11 years plus 313 days plus 17 hours 30 minutes;

[11] *Precession of the Equinoxes*: a slow rotation of the stars around the *Ecliptic Axis* (the axis of the apparent rotation of the Sun around the Earth) during a time interval of 26,000 years.

- the 7th layer of the sky was the celestial domain of Saturn, rotating from the west to the east with the circle completed in 29 years plus 155 days plus 6 hours 15 minutes;
- the 8th layer of the sky was the celestial domain of the 28 Constellations, rotating from the west to the east with the circle completed in 7,000 years;
- the 9th layer of the sky was a celestial domain without any heavenly object, rotating from the East to the West.

Why the Chinese astronomers, who had been studying the sky for more than three millennia, did not put to themselves the problem of a careful study of the structure of the sky over the Southern hemisphere? The reason is that, after Admiral Zheng He (郑和)[12] expeditions across the Indian Ocean and the Pacific Ocean, between 1405 and 1433, under the Ming Dynasty, the emperors of the subsequent Qing Dynasty did not feel the need to embark in risky maritime operations in distant territories located beyond the Equator Line, in such a way that Chinese astronomers had not the means to investigate about the structure of the sky over the Southern Hemisphere.

4. FROM THE GEOCENTRIC MODELS TO HELIOCENTRISM IN CHINA

The trading post of Macao (澳门 *Àomén*), located in proximity of the city of Canton (广州 *Guǎngzhōu*), in Southern China, had been created in 1557 A.D. (during the late Ming Dynasty) by the Portuguese Kingdom, which paid an annual rent to the Chinese rulers (who kept their jurisdiction on the territory). This agreement continued to hold until 1887 (Pannikar, 1953). The *St Paul Jesuit College* was created by the Portuguese in Macau in 1578-79, with the purpose of training Jesuit missionaries (sent there by the Jesuit Congregation in Rome) in Chinese language and culture. Those missionaries were not only religious people but, at the same time, linguists, geographers, mathematicians, astronomers and even artists, as the Italian Jesuit monk and painter Giuseppe Castiglione (1688-1766). In the time span of over two centuries the following Jesuit missionaries, among others, came to Macao: the Italian Matteo Ricci (1552-1610), the Germans Johann Schreck (1576-1630) and Johann Adam Schall von Bell (1591-1666), the Flemish Ferdinand Verbiest (1623-1688), the Pole Jan Mikolai Smogulecki (1610-1656) and the French Michel Benoist (1715-1774). Their arrival determined a turning point in Chinese astronomical sciences (Mungello, 2005).

Matteo Ricci , known in China as *Lì Mǎdòu* (利玛窦), arrived in Macao in 1588. He studied there, for several years, the Chinese language and thereafter compiled, with his colleague Michele Ruggieri (罗明坚 Luō Míngjiān), a founding father of the Jesuit Mission, a Chinese-Portuguese dictionary. Ricci also translated in Chinese, in cooperation with the Jesuit monk Sabatino De Ursis (熊三拔 Xióng Sānbá), parts of Euclid's "*Elements of Geometry*" as well as other Western mathematical and astronomical works. In 1601 he was invited into the Forbidden City by the Ming emperor *Wanli* (万历帝) (1563-1620), to become an adviser at the imperial court in recognition of his scientific abilities (chiefly due to his predictions of solar eclipses). Ricci never met the emperor, but the latter granted him patronage and supported Ricci's completion of China's first world atlas, the" *Record of Foreign Lands* " (职方外纪 *Zhifang Waiji*). Ricci died on 11 May 1610 and was buried first in a Buddhist temple; thereafter his remains were transferred to the *Zhalan Cemetery*, in Peking.

In spite of his great merits in transmitting his mathematical knowledge to Chinese scholars, Ricci, as a follower of the outdated *Ptolemaic* celestial model, wrote the following in his Chinese text, entitled "*The meaning of the universe (Cosmological Epitome)*" (乾坤体义 *Qiánkūn tǐ yì*), edited in 1608:

'*These nine layers [of sky] enclose each other like the layers of an onion. They are all solid, and the sun, moon, and the planets are fastened into their substance like the layers of an onion. They are all solid, and the Sun, Moon, and planets are fastened into their substance like knots in a board. Their motions are entirely due to those of their proper orbs. The celestial substance is clear and colorless, and thus transparent to light, in the same way as [light] is unimpeded by glass and crystal and the like*' (Sivin, 1995).

Jesuits missionaries continued to be accepted by emperor *Wanli* for their knowledge of astronomy, calendar-making, mathematics, hydraulics, and geography, but they were finally expelled by him from Peking during the last years of his reign. In 1627 the Jesuit Johann Schreck, known in Europe as *Johannes Terrentius* and in China as *Dèng Yùhán* (邓玉函),, who had studied Medicine in Freiburg and Mathematics and Astronomy in Paris and in Padua (under Galileo Galilei), was sent in 1618 to Macao, where he published in 1623 "*An Outline of Western Theories of the Human Body*)". Invited back to Peking by the new Ming emperor *Chongzhen*, he published there a treatise on Mechanics, entitled "*Diagrams and explanations of the wonderful machines of the Far West*". He died in 1630 and, as Ricci, was buried in the *Zhalan Cemetery.*

[12] During its first voyage to the Indian Ocean, an enormous fleet (composed of 317 ships, with 28,000 soldiers on board), sailed toward the Indian Ocean, reaching the Eastern coasts of Africa, the Red Sea, Japan and Korea. Between 1405 and 1433 Zhang He made a total of seven voyages. During the last one he visited the ports of Champa (Vietnam) and Java, as well as Palembang, Malacca, Ceylon and Calcutta.

The Scientific Revolution in Europe and its Impact on Chinese Cosmology during the 16th-18th Centuries

The Jesuit Johann Adam Schall von Bell, known in China as *Tāng Ruòwàng* (汤若望), studied Mathematics and Astronomy at the *Collegium Germanicum* in Rome, was sent to Macao together with Johann Schreck in 1618. He was later invited to Peking, in 1630, together with his colleague Giacomo Rho (1593-1638), known in China as *Luo Yagu* (罗雅谷), to continue the work of the deceased Johann Schreck on a reform of the Chinese Calendar. In cooperation with the Chinese astronomer Xu Guangqi[13], he participated in modifying the Chinese calendar and also compiled, from1638 to 1644, what is known as the *Chongzhen Calendar* (崇祯历 *Chóngzhēn lì*) (after the name of the last emperor of the Ming Dynasty). This calendar provided more accurate predictions of eclipses of the sun and the moon.

The Pole Jan Mikolai Smogulecki (1610-1656), who studied mathematics and astronomy at Freiburg, philosophy in Rome and law in Padua, moved to Macao in 1646. He taught there Astronomy and Mathematics, being the first to introduce the *Logarithms* in China. In 1653 he was invited by the first Qing emperor *Shunzhi* to his court, but soon later he requested permission to leave the court to continue his missionary travels and died in Zhaoqing in 1656.

When emperor *Shunzhi* died, in 1661, the Muslim court astronomer Yang Guangxian (1597-1669) accused him and his colleague Ferdinand Verbiest of having planned a rebellion, contributing to the death of the emperor's wife. In 1664 Yang took his place at the Imperial Astronomic Observatory, while the two Jesuits were imprisoned and condemned to death. Fortunately, a series of extraordinary events took place, among which a violent earthquake which destroyed part of the prison and of the imperial palace, while an extraordinary meteor was seen in the sky. For these reasons, the Emperor made them free and condemned to exile in Canton. Schall von Bell died within one year of his release.

The new Qing emperor *Kangxi* (1654-1722) recalled Ferdinand Verbiest back to Peking to replace Schall von Bell at the *Qing Astronomical Office*. The emperor became his friend and awarded him complete charge of the imperial astronomy observatory, which he rebuilt in 1673, designing six new astronomic instruments; the *Altazimut*h (used to measure the position of celestial bodies), a *Celestial Globe* (six feet in diameter, used to map and identify celestial objects), an *Ecliptic Armillary Sphere* (six feet in diameter, used to measure the ecliptic longitude and latitudes of celestial bodies), an *Equatorial Armillary Sphere* (six feet in diameter, used for measuring the true solar time), a *Quadrant Altazimuth* (six feet in radius, for measuring altitudes or zenith distances of celestial bodies) and a *Sextan*t (eight feet in radius, used to measure the angle of elevation of a celestial object above the horizon). Verbiest composed a table of all solar and lunar eclipses for the next 2000 years and died in Peking in 1688. He was buried in the *Zhalan Cemetery*.

Regarding the nature of the astronomical theories taught by the Jesuits in China until the middle of the 18th century, the sinologist Natan Sivin wrote the following in his "*Science in Ancient China: Researches and Reflections*" (Sevin, 1995):

'*Jesuit missionaries, who alone were in a position to introduce contemporary scientific ideas into China before the nineteenth century, were not permitted to discuss the concept of a sun-centered planetary system after 1616[14]. Because they wanted to honor Copernicus, they characterized his world system in misleading ways. When a Jesuit was free to correctly describe it in 1760[15], Chinese scientists rejected the heliocentric system because it contradicted earlier statements [by Jesuit astronomers] about Copernicus. No European writer resolved their doubts by admitting that some of the earlier assertions about Copernicus had been untrue*'.

The cause of the reticence of the Jesuit missionaries to propagate Nicolaus Copernicus' *heliocentric theory*, enthusiastically supported by Galileo Galilei, is due to the condemnation for heresy, by the Congregation of the Holy Office in Rome, of the work of Nicolaus *'Copernicus "On the Revolutions of the Heavenly Spheres*" in 1616, and Galileo Galilei's work "*Dialogue concerning the two chief world systems*" in 1633, with a ban on propagating anywhere these scientific works by Roman Catholic scholars.

Johann Schreck, in his "*Outline of Observational Astronomy*" (测天约说 Cètiān yuēshuō), wrote the following, without mentioning the name of Galileo Galilei:

'*In modern times a celebrated mathematician in a kingdom in the West has constructed a telescope, with which he has observed planet Venus. [He thus saw that] sometimes the planet is dark, sometimes fully illuminated, and sometimes a crescent illuminated either in the superior or inferior quarter. It was calculated that Venus moves as a satellite of the Sun …*'

[13] Xu Guangqi (1562-1633) was a Chinese agronomist, astronomer and mathematician during the Ming Dynasty. He was a collaborator of the Italian Jesuit Matteo Ricci.,

[14] 1616 is the year of condemnation of the Copernican System by the Holy Roman Inquisition', as mentioned in Chapter 2 of this paper.

[15] 1760 is the year when the Roman Holy Inquisition declared void the prohibition to publicly discuss Copernicus' Geocentric System, after Isaac Newton's publication of his "*Philosophiae Naturalis Principia Mathematica*" (*Mathematical Principles of Natural Philosophy*)", and its generalized consensus among western astronomers.

Another Jesuit missionary in China, Giacomo Rho (1592-1638), in his "*Principles of the Planetary Motion*" (五纬历指 *Wǔ wěi lìzhǐ*), published in 1634, was the first who illustrated to Chinese astronomers the compromise solution devised by the Danish astronomer Tycho Brahe , known as the *Tychonic System*, i.e. a mixed *Geocentric-heliocentric System*, where all the planets, excluding the Earth, revolved around the Sun, while at the same time they and the Sun revolved around the Earth.

Johann Adam Schall von Bell, in his text "*Speaking about the Telescope*" (远镜说 *Yuǎn jìng shuō*), published in 1640, didn't dare to mention Galileo's name, while introducing the use of the telescope. Later on, the Pole Jesuit Jan Mikolay Smoguleski , as well as the Flemish Ferdinand Verbiest, adopted the Tychonic System.

By the mid-eighteen century things changed. Owing to the work of Isaac Newton, "*Mathematical Principles of Natural Philosophy*", the new Celestial Mechanics had triumphed in the West and in 1757 the Roman Catholic Church lifted the ban on publishing the works of Nicolaus Copernicus and Galileo Galilei.

The first Jesuit astronomer who explicitly illustrated the Copernican Heliocentric System to Chinese astronomers was Michel Benoist (蒋友仁 Jiǎng Yǒurén), in 1761. Born in Dijon in 1715, he studied in Paris Mathematics, Astronomy, Architecture and Hydraulics and arrived in 1744 in China. He served for thirty years at the court of the *Qianlong* Emperor (1711-1799), devoting himself, among others, to architectural and landscape designs of the *Old Summer Palace*, together with his colleague (and emperor's advisor) the Italian Jesuit and painter Giuseppe Castiglione (1688-1766). In a letter to Europe, in 1764, he wrote:

'*I have already written you that, besides the hydraulic works with which I have been occupied for several years in the emperor's service, I have drawn a world map of which the two hemispheres with their margins are thirteen to fourteen feet in length by seven high. In 1761, when the fiftieth birthday of the reigning emperor Qianlong was being celebrated, I presented him with it. His Majesty received my present with kindness and kept me nearly an hour to ask me various questions on Geography and Physics…In my explanation I made a rather thorough exposition of the Copernican system, which was necessary because the Chinese had not yet adopted it.*'

The sinologist Sevin also writes that Benoist, in a second letter, provided a hint concerning the political motivation of his birthday gift to the emperor, in view of the intense rivalry existing between the French and the Portuguese missions of the Jesuit Company in Peking, related to the competition between the French and the Portuguese Kingdoms in the Far East:

'*I have added an explanation of the terrestrial as well as the celestial globe, of the new systems for the movement of the Earth and of the other planets, and on the movement of the comets, the return of which one hopes to succeed in predicting with certainty. I summarized the great enterprises ordered by our monarch for the perfection of arts and sciences, and especially for that of Geography and Astronomy, which were the subject of my writings. I described the expeditions sent to different parts of the world to observe various astronomical phenomena, to measure exactly the degrees of longitude and latitude of our globe …*'

Benoist did not declare that the *Copernican System* was true. He simply asserted that it was the only system in current use, having '*more precise conformity to calculations*'. Qienlong's response to Benosit was the following:

"*In Europe you have your way of explaining the celestial phenomena. As for us, we have ours too, without making the Earth rotate*".

Benoist died in Peking in 1774 and was buried in *Zhalan Cemetery*.

Since *Heliocentrism* had been until then unmentionable, Chinese scholars got an erroneous conception of *Copernicanism*, in such a way that they reject it at first. As a consequence, once the Roman Catholic Church removed the ban of the *Copernican System*, during the18th century, the Jesuit missionaries teaching it were accused to be agents of foreign powers and were no longer allowed to reside in Peking (with the exception of a small group of them, who were allowed to reside in the capital to serve the emperor in such fields as Cartography, Clockmaking and Optics). It took another century to Chinese astronomers to fully accept *Heliocentrism.*

The Chinese astronomer Ruan Yuan (阮元, 1764–1849) published in 1799 "*Biographies of Mathematical Astronomers*" (畴人传 *Chóu rén chuán*) and, in 1802/03 another one about Benoist's astronomical teaching, under the title "*World Map with Illustrated Explications*" (地球图说 *Dìqiú túshuō*), where the various Celestial Systems, the Ptolemaic, the Tychonic and the *Heliocentric* models were illustrated in detail.

About this issue, the eminent sinologist J. Needham observed the following:

> '*a continuing general and scientific progress manifested itself in traditional Chinese Society, but this was violently overtaken by the exponential growth of modern science after the Renaissance in Europe. China was homeostatic*[16], *but never stagnant.*' (Needham, 1995).

[16] *Homeostasis*: the tendency to maintain internal stability in an organism to compensate for environmental changes.

4. CONCLUSIONS

Before moving on to conclusions, it is appropriate to observe the following: every theory of Physics is based on some basic, unproven hypotheses (we could call '*postulates*') which support the entire theoretical apparatus. In the case of Aristotle and the *Aristotelians* after him, the fundamental postulate was that the physical entity called *Force*, responsible for the movement of a material object to which it is applied, is *proportiona*l to the body's *speed* (i.e. the ratio between the space traveled by the body and the time taken to travel it). Galileo Galilei, on the contrary, through his experimental method, proved that *force* is proportional to the body's *acceleration* (i.e. the ratio between its speed's variation and the time taken to accomplish it). If the *force* is equal to equal to zero (i.e. if no *force* acts on a body), then the body remains at rest or moves with *uniform rectilinear motion*: this is the famous '*inertia principle*'. In addition to that, Galileo assumed the following *postulates*: 1) '*on the Earth surface the space is homogeneous*' (i.e. the *gravity acceleration* of a body, on the Earth surface, is constant); 2) '*time flows uniformly*' (i.e. time flows with *constant speed*).

The first postulate was proven false by Newton's '*universal law of gravitation*'; the second postulate was proved false by Einstein through his '*Special Theory of Relativity*', which states that '*time's flowing speed decreases with the increasing speed of the moving body*' (as a consequence, at the light's speed '*c*' in an empty space, the time flow stops). An additional postulate has been assumed by Einstein's Relativity Theory: 'the light speed *c* in an empty space is the maximal one attainable by a moving body. Today, however, some theoretical physicists are studying the possibility that this insurmountable limit can be overcome, due to the *Quantum nature* of the empty space.

Passing now to the conclusions, we can venture to answer these questions:

- "*How can we explain the impetuous development of the Physical Sciences, Astronomy included, in Europe, starting with the 15th century?*"

Our possible answer is that the development of the natural sciences in Western Europe took place in strict connection with the cultural movement of *Humanism*, which moved the center of attention of scholars on man, '*blacksmith of his destiny*', stimulating a marked curiosity for nature and its laws. Another important factor were the maritime expeditions undertaken by the Portuguese and the Spanish Kingdoms, following the R*econquista* and, afterwards, by the kingdoms of England, the Netherlands and France, looking for new, economically profitable markets.

- "*Why did the Roman Catholic Church so harshly oppose the Heliocentric astronomical model, enunciated by Copernicus and confirmed by Kepler and Galilei?*"

Our answer is that the Roman Catholic Church felt under siege in those times, after the *schism* carried out by Martin Luther in Germany (which spread to Central and Northern Europe), by King Henry VIII Stuart in England, by the *Calvinists* in France, Switzerland, the Netherlands and Scotland. In the same centuries the *Turkish Sultanate* triumphantly advanced. from the Near East towards the heart of Europe, imposing the Muslim Religion in those formerly Christian countries. The Roman Catholic Church reacted with a *Counter-Reformation*, reiterating the concept that the interpretation of the Bible was the responsibility of the Church alone. Unfortunately, the Bible (written over two millennia earlier) says that the Sun revolves around the Earth!

The last question is the following: "*How can we explain the refusal by the Jesuit missionaries and astronomers Johann Schreck, Johann Adam Schall von Bell, Ferdinand Verbiest, Jan Mikolai Smogulecki to accept the Copernican System?*

The answer to this question is rather obvious: they were subdued to the authority of the Roman Catholic Church. In their defense, we must underline the fact that, adopting the Tychonic System and utilizing the astronomical telescope, they were able to formulate sufficiently accurate predictions of celestial phenomena.

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